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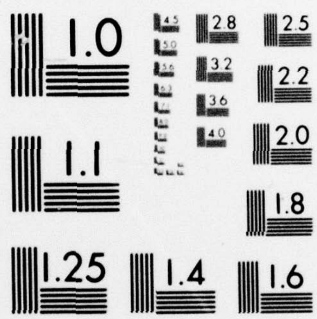

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SYSTEM OPTIMIZATION BY PERIODIC CONTROL

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Period: October 1, 1976 to October 1, 1977

Summary of Research Effort

The work undertaken during the period October 1, 1976 to October 1, 1977 was in two main areas: the theory and computation of periodic controls, and the input-output characterization of nonlinear systems. The second area impinges on the first since it offers new approaches to analyzing the effects of periodic forcing in nonlinear systems. The Bibliography gives a chronological listing of papers prepared during the year. Items (1, 5, 6, 7) were revised from earlier work for conference presentation or journal publication; items (2, 3, 4, 8) represent entirely new research. In what follows a brief description of research which was carried out will be given. It includes activities which go beyond (2, 3, 4, 8) and will be continued *into the coming year.*

The effort on periodic control was devoted almost entirely to: sufficient conditions for optimality, a computational study of periodic aircraft cruise, the use of variational models for analyzing the effect of system nonlinearities in the presence of periodic forcing. Item (3) extends the research in (1) and (6) by examining certain sufficient conditions for optimality in a general class of periodic control problems. These conditions give some indication of circumstances under which periodic control cannot improve performance. For example, improvement is impossible if the plant is modeled by linear differential equations and the cost functional is convex. This underlines the importance of understanding the effects of nonlinearities in periodic control problems. An interesting application of periodic control is aircraft cruise (Gilbert and Parsons, Journ. Aircraft, Vol 13, pp. 828-

830, 1976). An accurate fourth-order model of subsonic cruise was developed in non-dimensional form. Approximate analytical techniques, which were applied to the model, showed that periodic cruise might produce better performance in the presence of an *altitude constraint.* This led to the development of an algorithm for obtaining optimal periodic cruise trajectories. Preliminary computations have shown that in some cases (low drag, low wing loading) significant improvements in cruise performance are possible. The difficulty of the computations has shed light on issues concerning the development of general algorithms for solving periodic control problems. These issues will be investigated in the coming year. Also, when additional computations are finished, a report describing the results of the aircraft studies will be prepared . The Volterra transfer function offers an approach to evaluating the response of nonlinear systems with periodic forcing. Investigations of applications to periodic control was begun. It appears that tools of the type described in (7) are of value.

The investigation of input-output characterizations for nonlinear systems also has applications to the realization problem for nonlinear systems. Previous efforts on such problems have focused on algebraic techniques, and the research reported in (2,4,8), which is based on variational series, represents a departure. Necessary and sufficient conditions for the finite dimensional realization of bilinear and 2-power input-output maps are considered in (4,8). The problem of obtaining minimal order realizations for nonlinear systems is difficult and has not been solved previously. For the special case of single-input, single-output, continuous-time 2-powers, (2) gives the answer in a simple, useful form. These research directions were explored further with the help of A. E. Frazho who was a post doctoral researcher working on the grant during the summer months. Starting with ideas similar to those in (7, 8) the backward shift realization, used previously in the study of infinite-dimensional linear systems, was applied to multivariable 2-powers. Interesting results were obtained in both the infinite-dimensional and finite-dimensional cases. In fact, it appears that the backward shift approach offers notable advantages in the development of new algorithms for minimal realizations of both linear and polynomial nonlinear systems. This line of research is being continued and should lead to several reports in the coming year.

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